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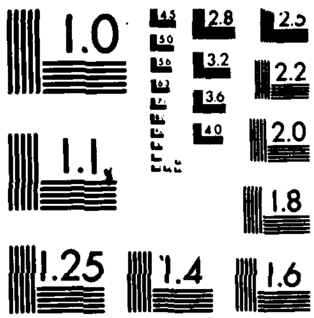

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ERROR IN CALSPAN® 3-DIMENSIONAL CRASH VEHICLE SIMULATION COMPUTER PROGRAM FOR THE CASE OF MASSLESS SEGMENTS

Marjorie R. Seemann

December, 1983

NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

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An error was recently discovered in the CALSPAN 3-Dimensional Crash Vehicle Simulation (3DCVS) computer program which causes gross errors in the results when massless segments are used. Additionally, even after the error had been corrected, unacceptable computational errors were evident in the 3DCVS output results when a massless segment was used. The sources of these errors were investigated and the significant findings and recommendations resulting from this investigation are presented in this report in order to make this information available to other CALSPAN 3DCVS users.

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ERROR IN CALSPAN® 3-DIMENSIONAL CRASH VEHICLE SIMULATION COMPUTER PROGRAM FOR THE CASE OF MASSLESS SEGMENTS

Marjorie R. Seemann

December 1983

Naval Medical Research and Development Command
Research Work Unit No. M0097PN001-5003

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SUMMARY

THE PROBLEM

The use of massless segments in CALSPAN® 3-Dimensional Crash Vehicle Simulation (3DCVS) computer runs was found to cause errors in the solutions to the system equations. An investigation into the source of these problems was therefore undertaken. The more significant results have been presented in this report so that other CALSPAN 3DCVS program users may have access to these findings.

FINDINGS

An error was found in the CALSPAN 3DCVS computer program which causes gross errors in the output results, but only when massless segments are used. Even after this program error had been corrected, small errors persisted in the solution. These small errors, which were evident only when massless segments were used, are apparently the result of the procedures used to solve the augmented system equations for massless segment cases, since such errors did not appear in the results obtained when essentially massless segments defined with extremely small mass and inertia components were used.

RECOMMENDATIONS

In order to successfully execute the CALSPAN 3DCVS program with a massless segment, it is essential that the program error indicated in this report be corrected. Additionally, even if the indicated correction is made, it is recommended that massless segments <u>not</u> be used in computer runs until the procedures for solving the system equations for this case have been modified to produce more accurate results.

ERROR IN CALSPAN® 3-DIMENSIONAL CRASH VEHICLE SIMULATION
COMPUTER PROGRAM FOR THE CASE OF MASSLESS SEGMENTS

INTRODUCTION

An effort was recently undertaken at the Naval Biodynamics Laboratory to implement the CALSPAN 3-Dimensional Crash Vehicle Simulation (3DCVS) computer program developed by Fleck et al. (1975) for use in our mathematical modelling. However, test cases in which a massless segment was used reflected gross errors, and the 3DCVS computer run terminated due to an error condition after only a few time increments. An investigation ensued to determine the source of the problems encountered when executing the program with massless segments. Some of the more significant results are presented in this report in order to make these findings available to other CALSPAN 3DCVS users.

METHOD

A CALSPAN 3DCVS test case was devised in which a massless segment was used to simulate a segment with a very small mass, since it was conjectured by Fleck, et al. (1975) that this might be a preferable way to handle such a segment, providing it could be sufficiently constrained to define the motion. Hence, the massless segment was connected by pin joints to each of two non-singular segments, since it was indicated by Fleck et al. (1975) that the use of such a configuration with a massless segment was feasible.

A second test case was also run using an essentially massless segment with extremely small mass and principal components of inertia, so that the results could be compared with the massless case.

The two test cases, each of which employed a three-segment, three-joint configuration, were defined as follows:

<u>Test Case I: Massless Segment.</u> For the massless segment case, segment 2 was defined as massless with a zero inertia tensor. This massless segment was connected by pin joint 1 to segment 1 and by pin joint 2 to segment 3, where segments 1 and 3 were each defined with positive mass and principal inertia components.

<u>Test Case II: Segment with Extremely Small Mass and Inertia Components.</u> For this case a non-singular, but essentially massless segment was used, with the weight of the segment defined as 1.0×10^{-7} N. and with each principal inertia component defined as 1.0×10^{-7} N-M-S^2. Segments 1 and 3 and the joints were identical to those used in Test Case I.

RESULTS AND ANALYSIS

The investigation into the reason for the discrepancies in the computer output results for the massless segment case revealed that it was caused by an error in the original CALSPAN 3DCVS computer program, which manifests itself only when massless segments are used. It was found that the reduced set of system equations solved by subroutine FSMSOL was erroneously assumed to be symmetric. The matrix of coefficients of the reduced set of solution variables is usually symmetric in the absence of singular (massless or inertialess) segments and other unusual cases. However, in the case of singular segments the reduced set of system equations solved in subroutine FSMSOL is augmented to include the solution for the linear and angular acceleration components of the singular segment, in addition to the other variables normally solved for, that is, the components of the joint forces, joint torques, etc. The coefficients of the linear and angular acceleration components for the singular segments in the augmented system equations are defined in subroutine DAUX55, which is called only when singular segments are used. The definition of these coefficients guarantees a non-symmetric coefficient matrix for the reduced system equations and therefore invalidates the assumption of a symmetric matrix.

It should be noted that the reason that the coefficient matrix was erroneously assumed to be symmetric is that an internally set index, MJ2, in the calling arguments of subroutine FSMSOL was erroneously set to a positive value in subroutine DAUX. In order to correct this error a modification was made to subroutine DAUX, by which the index MJ2 is set to negative value in the case of singular segments, since this is the requirement for a non-symmetric coefficient matrix. It should also be noted that the option to treat the coefficient matrix as symmetric was added to the CALSPAN 3DCVS program by the developers Fleck et al. (1975) after the logic for massless segments had been added to the program, and that the symmetric option was included only to save computational time.

After the above-discussed correction had been implemented in the program, the coefficient matrix for the case of the massless segment was then correctly treated as non-symmetric, and dramatically improved and relatively consistent results were then obtained, and the system equations were satisfied reasonably well. Furthermore, the computer run did not terminate prematurely due to an error condition, as it had previously done, and reasonable results were obtained for the 260 msec run duration. However, small but noticeable computational errors were evident in the solution. For example, the inertial linear acceleration components at joint 1 calculated independently using the computed kinematic variables for each of the segments connected by the joint were reasonably close, but not identical, as may be seen in Table 1. Small errors in the joint forces are also evident in the results presented in Table 2. It should be noted that in the case of the massless segment the only forces acting on the segment are the joint forces, which must be equal in magnitude and opposite in direction in order to satisfy the system equations. However, It may be seen in Table 2 that the joint forces for the massless segment computed at joints 1 and 2 were almost, but not quite equal in magnitude.

On the other hand, when the non-singular but essentially massless segment was used, these computed forces were indeed equal, to the extent of the four decimal places in the printout, as indicated in Table 4. In addition, identical linear acceleration components (to the degree of accuracy in the computer printout) were computed at each joint based on the kinematic variables for each segment connected by the joint, as may be seen in Table 3.

The small discrepancies in the solution parameters in the case of massless segments are apparently the result of the procedure used in subroutine FSMSOL to solve the augmented set of reduced system equations in which a Gaussian elimination is used, starting at the lower right corner of the coefficient array. A check on some of the computations made in FSMSOL revealed that in back-solving for the components of joint force at joint 1, nearly equal immense numbers (on the order of 1×10^{18}) with different signs were combined. Of course, computations of this type necessarily result in the loss of many (if not all) of the significant digits of accuracy in the results, even when double precision calculations employing up to eighteen significant digits of accuracy are used.

CONCLUSIONS AND RECOMMENDATIONS

The small errors which persist in the CALSPAN 3DCVS program output even after an obvious program error had been corrected cast serious doubt on the feasibility of using massless segments in computer runs. It is therefore recommended that massless segments not be used in modeling efforts employing the CALSPAN 3DCVS program *unless/until* the procedures for solving the system equations are modified to produce more accurate solutions. It should be noted that in response to our findings Dr. Fleck (Fleck et al., 1975) has indicated in a letter to the author that he concurs with the conclusions and recommendations presented in this report.

REFERENCES

1. Fleck, J. T., Butler, F. E. and Vogel, S. L., "An Improved Three Dimensional Computer Simulation of Motor Vehicle Crash Victims," NHTSA Report Nos. DOT-HS-801-507 through 510 (4 volumes), National Technical Information Service, Springfield, VA (Accession Nos. PB-241692, 3, 4 and 5), April 1975.

TABLE 1. COMPUTED JOINT INERTIAL LINEAR ACCELERATION - MASSLESS SEGMENT USING CORRECTED VERSION OF CALSPAN

CASE I - SEGMENT 2: MASS = 0.0 Kg
PRINCIPAL MOMENTS OF INERTIA = 0 N-M-S^2

JOINT	SEGMENT USED TO COMPUTE JOINT ACCEL	INERTIAL LINEAR ACCEL. OF JOINT (M/S^2)		
		X	Y	Z
1	1	0.346	-0.089	-0.035
1	2	0.377	-0.097	-0.039
2	2	0.689	-0.178	-0.071
2	3	0.689	-0.178	-0.070

TABLE 2. JOINT FORCES ON MASSLESS SEGMENT USING CORRECTED VERSION OF CALSPAN

CASE I - SEGMENT 2: MASS = 0. Kg
PRINCIPAL MOMENTS OF INERTIA = 0. N-M-S^2

JOINT	FORCE (N.)		
	X	Y	Z
1	-3.2813	0.8988	-33.7528
2	3.2176	-0.7922	33.6167

TABLE 3. COMPUTED JOINT INERTIAL LINEAR ACCELERATION - SMALL MASS AND INERTIA COMPONENTS

CASE II - SEGMENT 2: MASS = 1. X 10^{-8} Kg
PRINCIPAL MOMENTS OF INERTIA = 1.0 X 10^{-7} N-M-S^2

JOINT	SEGMENT USED TO COMPUTE JOINT ACCEL	INERTIAL LINEAR ACCEL. OF JOINT (M/S^2)		
		X	Y	Z
1	1	0.419	-0.108	-0.043
1	2	0.419	-0.108	-0.043
2	2	0.695	-0.179	-0.071
2	3	0.695	-0.179	-0.071

TABLE 4. JOINT FORCES ON SEGMENT WITH SMALL MASS AND INERTIA COMPONENTS

CASE II - SEGMENT 2: MASS = 1.0 X 10^{-8} Kg
PRINCIPAL MOMENTS OF INERTIA = 1.0 X 10^{-7} N-M-S^2

JOINT	FORCE (N.)		
	X	Y	Z
1	-3.2370	0.7973	-33.6152
2	3.2370	-0.7973	33.6152

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